

NUWC Newport Leads Navy Research of Fuel Cell Technology

Innovative Power Sources Sought to Extend Operating Range of AUVs

AS NAVY REQUIREMENTS

expand in the undersea domain for autonomous systems with long endurance, Naval Undersea Warfare Center (NUWC) Newport is playing a key role in the development of air-independent propulsion systems.

Autonomous Undersea Vehicles (AUV) have the capability to venture where other platforms cannot, providing a standoff distance that allows the warfighter to operate in contested areas while remaining out of harm's way. The U.S. Navy uses AUVs for many diverse tasks, including intelligence, anti-submarine warfare, and mine countermeasures. Military AUVs are most effective when they can execute missions independently for extended periods of time ranging from tens to hundreds of hours, and as such, require high-energy, air-independent propulsion (AIP) sources. AIP refers to any underwater, non-nuclear

propulsion system that operates without the need for atmospheric oxygen.

Historically, the Navy has employed more traditional battery technology for its low-power AIP applications. However, the longer standoff distance necessary for AUVs to complete missions successfully requires a novel power source beyond current lithium battery technology. Fuel cells are a likely prospect, but those being developed by industry for consumer products are not addressing the unique needs of the submarine fleet because they typically rely on the consumption of air as an oxygen source. Investment in basic and applied research at Navy laboratories is required to address the unique challenges associated with the AIP environment.

The Office of Naval Research (ONR) regards NUWC Newport as the Navy's

underwater experts in the field of AIP for AUVs, and has tasked them with finding alternate methods of powering these unique vehicles.

Dr. Joseph Fontaine, head of NUWC Newport's Undersea Vehicles Propulsion and Energy Branch, leads a team of research engineers and scientists who are exploring safe long-endurance power sources for underwater systems.

"In general, the group works on air-independent energy sources for underneath the water line, from sensors requiring low power to torpedoes requiring considerably more power," says Fontaine. "For high-power systems, they use thermal combustion engines and power-dense batteries activated by seawater. AUVs are middle-of-the-road and fit into the spectrum for low-to-medium power levels, which are typically best suited for batteries and fuel cells."

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Currently, AUVs rely on lithium ion batteries to meet their energy requirements; however, as witnessed in previous naval applications and consumer products, the risk associated with a lithium battery failure can be catastrophic. NUWC Newport is collaborating with the Naval Surface Warfare Center Carderock, Maryland and the Naval Surface Warfare Center Crane, Indiana—the Navy’s subject matter experts in lithium ion batteries—to provide a systems engineering solution for safely integrating this technology onto AUV platforms.

The Promise of Fuel Cells

As AUV requirements continue to expand, fuel cells, which can potentially double the range of lithium ion-powered systems, are being considered as an energy source. Several types of fuel cells exist, but the Navy is currently focused on proton exchange membrane (PEM) fuel cells for AUVs.

A fuel cell converts chemically stored energy into electrical energy via a direct electrochemical reaction. This differs from a more traditional thermal based system (e.g., automotive engine, electrical power plant, etc.) where the fuel and oxygen are combusted to produce heat which is then converted to electricity via an energy converter (i.e., generator, etc.). PEM fuel cells use hydrogen as a fuel source, which is combined with an oxygen source (e.g., liquid oxygen, hydrogen peroxide, etc.). Besides the efficiency advantage of directly converting a fuel and oxidizer to electricity, water is the only byproduct of the reaction. Higher voltage is achieved by connecting multiple fuel cells in series to make a fuel cell stack,



Christian Schumacher holds the metal hydride alloys that may power AUVs.

James Travassos

similar to connecting batteries in series. Higher amperage is achieved by increasing the area of the fuel cell stack, similar to how batteries are connected in parallel. The result is a low-waste, high-efficiency, zero-emission source of propulsion with near-silent operation.

Previously, the Navy investigated the use of solid oxide fuel cells (SOFC) for AUV applications. The most significant difference between PEM fuel cells and SOFCs is their energy source and operating temperature. SOFCs can be powered by more than one kind of fuel, such as clean diesel, carbon monoxide, methane, hydrogen, and jet propellant, which notably is already onboard surface ships to power aircraft and helicopters. The use of higher-level hydrocarbons requires reforming to break them down to hydrogen and carbon monoxide for electrochemical conversion to water and carbon dioxide in the fuel cell. The operating tempera-

ture is typically in the 800 degrees Celsius range; however, SOFC-based systems for air-independent applications typically are more complex, incorporating several subsystems.

A more mature technology, PEM fuel cells provide greater than 50 percent efficiency, lower temperature operation, fast start-up, minimal balance of plant (components that are needed to operate the fuel cell such as blowers to circulate the hydrogen and oxygen, heat exchangers, and valves) and increased reliability (thousands of hours). The main challenge is the fuel source—very pure hydrogen, typically more than 99.999 percent hydrogen. The terrestrial method of employing a PEM fuel cell is to put it in a stationary place and bring in air from the outside. NUWC Newport’s efforts include the assessment and development of an additional oxygen storage/supply subsystem because they will be operating air independently. Each potential combination of

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fuel/oxidant comes with a unique set of advantages and challenges—the balance between risk and reward is being refined to find the solution that meets both the technical requirements and the desired safety and logistical demands.

of compressed hydrogen along with the extremely low temperatures associated with cryogenic hydrogen (minus 423 degrees Fahrenheit) limit their suitability for AUV applications. This is further exacerbated by the challenges associated with safety,

says Schumacher, “So I started looking into metal and chemical hydrides for hydrogen storage.”

After conducting a literature review, he became interested in metal hydrides, which work like a sponge and enable hydrogen to be stored at lower pressure (less than 500 psi) and pose a much lower safety risk. Schumacher is investigating metal hydride alloys similar to those used in the German U212 submarine, which is powered by a Siemens PEM fuel cell system. These submarines use a hybrid diesel/PEM fuel cell, with the PEM fuel cell utilized while submerged.

“We are scaling this technology to a large-sized AUV,” says Schumacher. The commercially available hydrides need to be containerized properly for use on a Navy vessel. These hydrides provide good volumetric storage of hydrogen, but are too heavy for most applications since AUVs need to be neutrally buoyant. For smaller systems, Schumacher is researching chemical hydrogen storage systems such as aluminum hydride (AlH₃), commonly known as Alane.



The NUWC Newport fuel cell team. Back row: Dr. Charles Patrissi, Dr. Craig Urian, Dr. John Izzo. Front row: Christian Schumacher, Dr. Joseph Fontaine, Jennifer Rizzo.

James Travassos

Adapting Existing Technology

NUWC Newport research engineer Christian Schumacher is investigating emerging technologies to store hydrogen. Two options being investigated for commercial applications include high-pressure gaseous reactant storage and liquid hydrogen. However, the weight of the pressure vessel and general low storage density

shock, vibration, and implosion in an undersea environment.

“For PEM fuel cells, using compressed hydrogen for large AUVs does not provide energy levels that are significantly better than batteries on a systems level along with operational safety concerns associated with 10,000 and 15,000 pounds per square inch (psi) pressure vessels,”

Safety & Testing

Schumacher’s goal is to develop a pragmatic, safe, Fleet-focused solution for fuel cell reactant storage and delivery that can pass the Navy’s “High Energy Systems Safety Manual” safety certification process. He has been instrumental in crafting the interim guidance for future safety testing and certification of future fuel cell systems.

Dr. John Izzo, a team member of the Propulsion and Energy group, conducts research and analysis of fuel cells, batteries, and additional energy systems, and serves as the test director for AIP at NUWC Newport. The group develops the test protocols, standard operating procedures, required safety packages (typically analysis for explosive atmospheres and oxygen safety), and data acquisition systems; and performs design /analysis to support the test and integration of the test item into the facility.

“Our role is to help develop fuel cell technology,” states Izzo. “There’s still work that has to be done to get fuel cells into the Fleet. There has to be enough of an improvement over lithium batteries to make fuel cells worth pursuing. They also have to be certified for safe operation and storage aboard a Navy platform.”

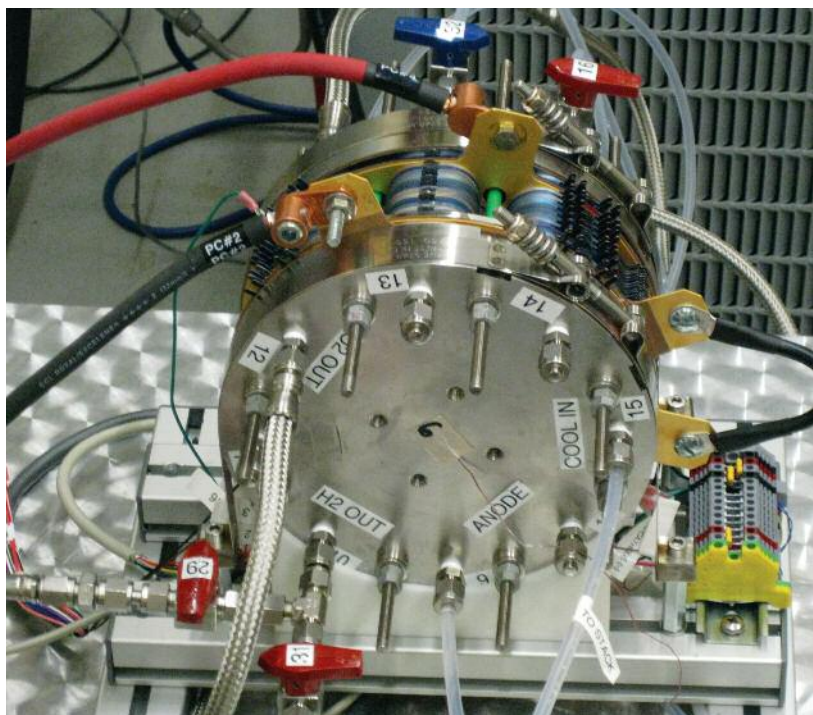
As NUWC Newport research engineers identify and investigate new technologies to power Navy vehicles, their role is not only to develop new concepts, but to analyze ideas and prototypes from their industry counterparts, as well as conduct trade studies in support of ONR, the Naval Sea Systems Command, the Defense Advanced Research Projects Agency, the Department of



Dr. John Izzo is NUWC Newport’s Test Director for AIP.
James Travasso

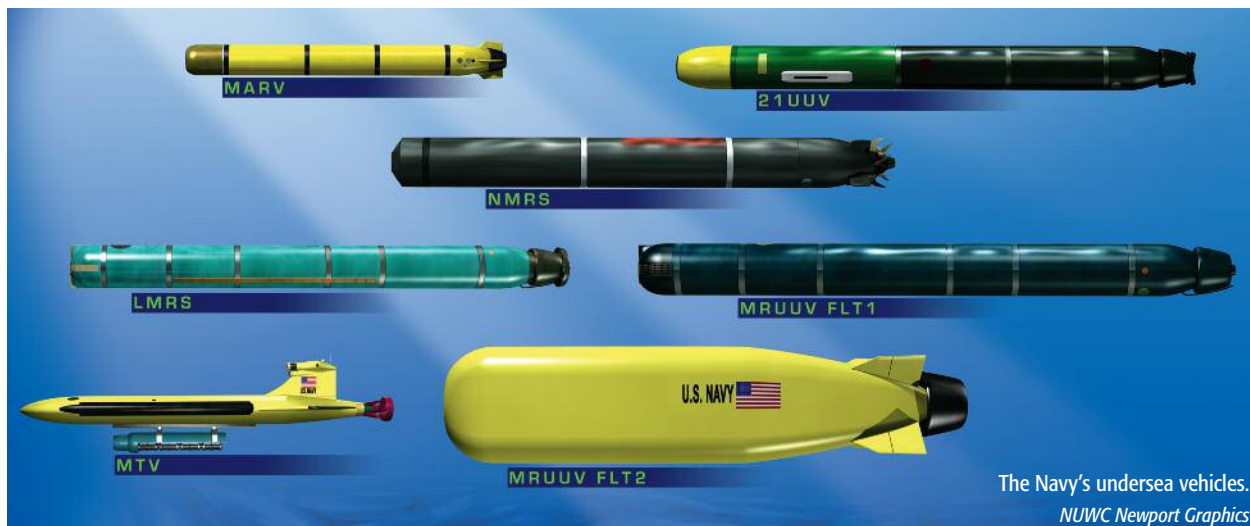
For More Details

IN ADDITION TO testing alternative energy systems, NUWC also serves as a model for energy conservation itself by utilizing a utility energy services contract with their local utility provider. For details, read “NUWC Newport Partners with National Grid to Tackle Energy Conservation: Annual Energy Savings of Plan Estimated at \$1.5 Million” in the summer 2014 issue of *Currents* at <http://greenfleet.dodlive.mil/currents-magazine>.



Small-scale prototype of a non-flow-through PEM fuel cell utilizing internal, responsive, product water management technology.

Christian Schumacher



Energy, the U.S. Army, and the National Aeronautics and Space Administration.

More About NUWC

NUWC Newport's test facility was designed specifically to evaluate high-energy systems being developed for AUVs beyond lithium ion batteries. It is equipped to conduct fuel cell and thermal system testing, materials development and evaluation, battery design and prototyping, simulated undersea testing, prototype system integration, and reactor design and testing.

NUWC Newport is able to perform rigorous testing on each system and subsystem and provide the Navy with a comprehensive assessment of the technology. These systems typically involve a unique set of requirements that differ from test to test. The flexibility that has been designed in NUWC Newport's test facility is essential. The team lends their unique expertise and provides the technical oversight for determining which sources work best for different applications.

NUWC Newport has served as the Navy's principal test and evaluation laboratory for over a half a century in the area of test and evaluation of AIP energy systems for undersea vehicles from the component level to simulated operating ocean depths. Their test facilities include the Deep Depth Test Facility which is specifically designed to simulate deep ocean depths while conducting operational testing of torpedo propulsion systems and other battery-based systems. The test facility team at NUWC Newport specializes in test and evaluation of technologies ranging

from Otto fuel (monopropellant used to power torpedoes) to silver zinc batteries, flowing seawater-based aluminum silver oxide batteries, Stored Chemical Energy Propulsion System-based systems, and, most recently, the ability to test both PEM- and SOFC-based systems using oxygen sources ranging from air to 100 percent oxygen.

This knowledge base is currently being leveraged to the benefit of the next generation of more efficient and more energy-dense AIP solutions that could include fuel cell system technology, which will be constrained by many of the same operational issues of the legacy systems. In addition to SOFCs and PEM fuel cells, testing has included thermal engines, and system subcomponents such as power-dense direct-current motors and reactant delivery systems. Their research, which is tested under unique and extreme conditions, has contributed to the advancement of fuel cell technology.

The fuel cell stacks and other energy sources are examined with the expectations of the Fleet in mind. Different tech-



Christian Schumacher briefs NUWC Newport personnel on the latest fuel cell research.

David Stoehr

ONR's Future Naval Capabilities Program

INITIATED BY THE Department of the Navy in 2002, the FNC program is a science and technology program designed to develop and transition cutting-edge technology products to acquisition managers within a three- to five-year time-frame. Through the FNC program, ONR proposes technology investments called enabling capabilities to address science and technology gaps.

The program has nine functional areas:

1. Capable Manpower

Intuitive systems and personnel tools for matching Sailors and Marines to the right jobs and training for mission-essential competencies.

2. Enterprise and Platform Enablers

Cross-cutting technologies to lower acquisition, operations, and maintenance costs.

3. Expeditionary Maneuver Warfare

Naval ground forces with special emphasis on regular and irregular warfare.

4. Force Health Protection

Medical equipment, supplies and procedures to reduce morbidity and mortality when casualties occur.

5. FORCEnet

C4ISR, networking, navigation, decision support and space technologies that provide an architectural framework for naval warfare in the information age.

6. Power and Energy

Energy security, efficient power and energy systems, high energy, pulse power.

7. Sea Basing

Logistics, shipping and at-sea transfer technologies that provide operational independence.

8. Sea Shield

Missile defense, antisubmarine warfare, mine warfare and fleet/force protection technologies that provide global defensive assurance.

9. Sea Strike

Weapons, aircraft and expeditionary warfare technologies that provide precise and persistent offensive power.

nologies and subcomponents are compared, and the team determines how well the fuel cell stacks work, as well as how safe and useful they might be on Navy platforms. As these technologies progress, NUWC Newport is writing the rules for implementation into naval platforms, with the safety of the warfighter being their highest priority.


"Safety is a big focus," says Izzo. "It has to be safe. We can't put the platform at risk. There is some level of risk that is accepted but it has to be tempered. There's a long list of safety requirements for high-energy systems."

NUWC Newport's work addresses "Power and Energy," one of the pillars of ONR's Future Naval Capabilities (FNC). Their research also touches on ONR's Innovative Naval Prototypes, which are defined as "high-payoff, high-risk, game-changing, emerging technologies that define the Navy's future battlespace." PEM fuel cells can potentially power large-sized AUVs by providing new AIP systems and core vehicle technologies to extend endurance to months of operation time.

"Other groups are working with hydrogen storage technologies," states Fontaine. "Because of our experience in the energetics field, fuel cell development and underwater

systems engineering, we're able to guide the emerging technology through the safety certification process."

For NUWC Newport, the overarching goal is to power AUVs for long periods of time so they can conduct longer missions without stopping for re-charge.

"The NUWC Newport team is conducting critical research, testing, and evaluation to advance fuel cell technology and improve the mission endurance of AUVs," said Rear Admiral Moises DelToro III, Commander, NUWC Newport. "Their work will allow AUVs to operate for extended periods of time as a force multiplier and keep our warfighters out of harm's way. This technology has the potential to benefit the Fleet immensely." 

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